II

The Disk-Halo Interface in other Galaxies

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

LARGE SCALE STRUCTURE OF HI IN OTHER GALAXIES

THIJS VAN DER HULST AND JURJEN KAMPHUIS
Kapteyn Astronomical Institute, Postbus 800,
NL-9700 AV Groningen, The Netherlands

ABSTRACT. In this paper we discuss the large-scale structures (> 500 pc) of the neutral atomic hydrogen in the disk of nearby galaxies, with an emphasis on finding evidence for neutral gas features in the disk - halo interface. Most nearby galaxies studied in detail appear to have hole and shell type structures in their HI disks and several show evidence for gas at peculiar velocities, probably examples of gas streaming out of the disk into the halo. Not all of the observed phenomena can be explained by stellar winds and supernova explosions and other explanations will briefly be discussed.

INTRODUCTION

In the last decade many observational and theoretical studies of the interstellar medium in our Galaxy have uncovered a large variety of phenomena, features and processes which play a role in shaping the HI layer. Good examples are the shell- and worm-like structures found by Heiles (1979, 1984). It is believed that these structures are located in the disk and probably have extensions perpendicular to the plane of the disk. The origin of these structures is uncertain. Heiles searched for correlations between shells and OB associations or HII regions and concluded that there was no one-to-one correspondence between the shells and supershells and any other known population of astronomical objects.

In particular the supershells, all located in the outer Galaxy, show a complete lack of association with young stellar populations. The diameters and the kinetic energies of the largest shells are a few kpc and 10^{53} - 10^{54} ergs. Collective stellar winds/supernova explosions are barely sufficient to create these large HI cavities. An alternative explanation is the infall of gas clouds (Tenorio-Tagle et al. 1987, Tenorio-Tagle and Bodenheimer 1988), which more efficiently produce the mechanical energy necessary to drive out the huge HI shells. Evidence for collisions of gas clouds with the Galactic disk has been provided by Heiles (1984), Mirabel and Morras (1990) and Mirabel (cf. this volume). An excellent review of the different properties and the different physical models for the worms and shells

H. Bloemen (ed.), The Interstellar Disk-Halo Connection in Galaxies, 201–212.
© 1991 *IAU. Printed in the Netherlands.*

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

can be found in e.g. Heiles (1990). The presence of shells and worm-like features suggests that neutral gas can be brought into the halo of the galaxy. The idea that neutral gas exists in the Galactic halo is of course not new: the since long known High Velocity Clouds (HVCs), HI with peculiar velocities ($V_{LSR} > 70$ km sec^{-1}) at high latitudes, are such a 'halo' population of gas clouds. These clouds are now known to cover a large part of the sky and consist of complexes in a variety of sizes, up to several kpc (for review see cf. van Woerden et al. 1985, Wakker 1990 and this volume). Since the distances to these clouds are unknown, masses, energies and origins are uncertain. The structure of a large fraction of the HVCs can be explained in terms of a galactic fountain model (Bregman 1980, Wakker 1990). The very high velocity clouds, however, are more likely associated with the Magellanic Stream and originate from a tidal interaction with the Magellanic Clouds (Wakker 1990).

In this review we will examine the situation in other galaxies with the question in mind: do other galaxies show the same type of phenomena and if so what can we learn about their origin? Wakker et al. (1989) made a first attempt to search for high velocity gas in existing HI databases of three nearby galaxies, but found no clear examples. As a result of the improved sensitivity of modern synthesis radio telescopes such as the Very Large Array (VLA) and the Westerbork Synthesis Radio Telescope (WSRT) it is now possible to detect HI masses of about 10^6 - 10^7 $M_\odot$ in nearby (D < 10 Mpc) galaxies. For comparison, if we assume that the Galactic HVCs are at a distance of 10 kpc above the plane, the HI masses of the largest HVC complexes are of the order 10^7 $M_\odot$ (Wakker 1990). In addition, the 'chimney' theory (Mac Low, McCray and Norman 1989) predicts that about 5 - 10% of the swept up material in a superbubble will be cold gas blown out into the halo. This implies that we should be able to detect objects like the large HVC complexes and the upper extreme of the superbubble range in other nearby galaxies from such sensitive synthesis observations.

The most suitable objects to search for HI outside the main disk are face-on and edge-on galaxies. The advantage of the edge-on galaxies is that one can directly observe gas high above the disk. Observing face-on galaxies on the other hand does yield information about the velocities of the gas in a direction perpendicular to the disk.

Radio telescopes such as the VLA and the WSRT have spatial resolutions up to $\approx 10''$ corresponding to about 500 pc at a distance of 10 Mpc. This implies that one could distinguish objects like the Heiles' supershells out to such a distance, but that the smaller HI features could only be well resolved in Local Group galaxies. Another consequence of the limited resolution is that beyond 5 Mpc one expects to only detect break-through or blow-out holes assuming that the thickness of the cold neutral medium is about 350 pc like in our Galaxy.

We will first review the evidence for HI at high distances above the plane from observations of edge-on galaxies and then discuss the presence of large holes and HI at peculiar velocities in face-on galaxies.

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

HI AT HIGH DISTANCES ABOVE THE PLANE

Edge-on galaxies offer the best perspective for finding HI cloud complexes at large distances from the plane and for finding features which extend from the plane to high z distances. A few galaxies have been observed in detail recently. These are NGC 3079 (Irwin and Seaquist 1990), NGC 891 (Broeils, Sancisi and van Albada, in preparation; Rupen, in preparation) and NGC 4565 (Rupen, in preparation).

NGC 3079 is a galaxy (D = 10 Mpc) with an active nucleus and has a peculiar distribution of non-thermal radio emission showing two radio lobes along the minor axis (Duric et al. 1983 and references therein). Irwin and Seaquist (1990) observed the galaxy in HI and found 15 extensions, which may be the equivalent of the worms and shells found in our Galaxy by Heiles (1979, 1984). These extensions are randomly distributed over the HI disk and not concentrated toward the nuclear region, so that a relation with the non-thermal nuclear activity is unlikely. In addition they found 5 arcs, 2 to 6 kpc in size, in the outer regions of the galaxy. Here, however, the situation becomes confused because of the warp of the galaxy.

Other edge-on galaxies observed in detail are NGC 4565 and NGC 891. Both show extensions to moderate distances from the plane ($\approx$ a few kpc) at marginal column density levels. NGC 891 has been observed in Hα by Rand et al. (1990) and Dettmar (1990), and at very low level they detect spurs of ionized gas extending to $\approx$ 2 - 4.5 kpc in z. No clear correlation exists between the Hα filaments and extensions seen in the HI. Perhaps we need to look deeper, at lower column density levels, and work on a new, very sensitive WSRT observation is in progress. The existing data of Broeils et al. do, however, reveal one promising case of a gas feature extending out to 5 kpc in z.

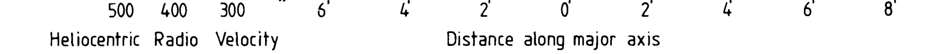

Figure 1. Contour map (b) of the total column density distribution of NGC 891 (contour levels are 1.6, 3.2, 6.4, 12.8, 19.2, 25.6, 32.0, 38.4, 44.8$\times10^{20}$ cm^{-2}) at 13″$\times$19″ resolution and, at the left, the position - velocity diagram (a) integrated over the high z gas (contour levels are 2.5, 5, 10, 20, 40, 80, 120, 160 mJy/beam). The integration interval is given by the bar in (b).(Image courtesy: A. H. Broeils)

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

Figure 1 shows the integrated HI map of NGC 891 (b) and a position-velocity map (a) integrated along the high-z feature indicated on Figure 1a. The position-velocity map does show a clear continuity in velocity, suggesting strongly that this feature is real and that the high z gas may be related to phenomena in the disk. The precise connection with the disk is, however, not yet clear and until more examples of this kind are found one could only speculate.

HOLES

If galaxies have a general flow of material from the disk into the halo produced by winds and supernova explosions, one would expect to find holes and cavities in the HI layer. Face-on galaxies are ideal objects to search for such effects. The first examples of holes are the expanding HI shells found in the SMC by Hindman (1967). Allen and Goss (1979) noted the existence of large holes with diameters of about 1 to 5 kpc in the giant Sc galaxy M 101. Since then more information has become available on nearby galaxies and the existence of holes, near-holes and shells in the HI distribution of galaxies appears to be more common than originally thought.

HI observations of the Large Magellanic Cloud (McGee and Milton 1966, Rohlfs et al. 1984) show several large holes. In the LMC at least 5 out of the 9 Hα supershells (Meaburn 1980, Meaburn et al. 1987) are associated with HI holes or loop-like features (Dopita, Mathewson and Ford 1985). The HI masses in the shells are in the range 6 - 25 10^6 $M_\odot$.

Brinks and Bajaja (1986) searched the HI observations of the Sb galaxy M 31 for holes and found 141 examples. Most of these are roughly elliptical in shape with sizes ranging from 100 pc (the resolution limit) to $\approx$ 1 kpc. The missing HI mass in the largest holes is of the order of a few 10^6 $M_\odot$. The estimated energies and ages of these largest holes determined, assuming that the surrounding HI gas is in the snowplough phase, are 10^{52} - 10^{53} ergs and about 10^7 years, respectively. None of these holes should be classified as a supershell, especially because the largest holes are probably inter-arm regions. Only the smaller (< 300 pc) holes are associated with OB associations. The larger holes do not clearly show this association with star forming regions, a fine exception being the hole around the OB association NGC 206 (Brinks 1981). One should keep in mind, however, that the inclination of M 31 is not very favourable and the spiral arms are mostly seen superposed on one another.

In M 33, considerably more face-on than M 31 though still inclined by 59 degrees, Deul and den Hartog (1990) found 148 holes in the HI distribution. The sizes of these holes range from 40 pc (the resolution limit) to 1 kpc, with a tendency for the largest holes (probably all inter-arm regions) to be located at larger galactocentric distances. Although the starformation rate in M 33 is higher than in M 31, the distribution, sizes, energies and missing masses of the holes are very similar. Deul and den Hartog found a correlation between the holes and the distribution of OB

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

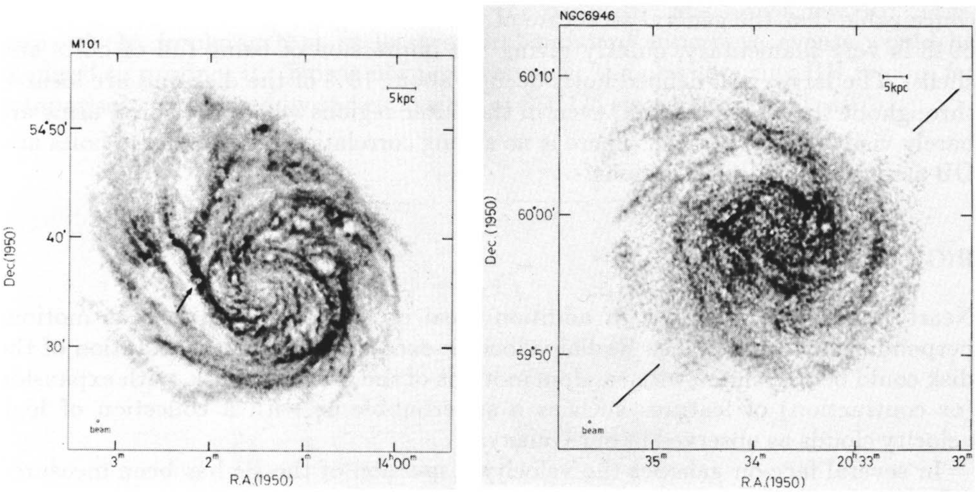

Figure 2. Grey-scale picture of the total HI column density distribution of M 101 (13″×16″ resolution, left panel) and of NGC 6946 (13″×16″ resolution, right panel). The arrow in the left panel gives the position of the superbubble near NGC 5462 (see Figure 3) and the line in the right panel indicates the position angle of Figure 4 and crosses the high velocity gas and elongated hole at $\alpha = 20^h\ 33.4^m\ \delta = 59°\ 59.4'$.

associations and some correlation with the distribution of Hα emission. The larger holes, however, anti-correlate with the distribution of recent star formation.

Another example of a galaxy with large holes in the HI is the nearby dwarf irregular galaxy IC 10, where Shostak and Skillman (1989) found seven holes. Two of these holes have diameters larger than 500 pc. The energy input derived is 5 10^{52} - 3 10^{53} ergs. The largest holes correspond to the supershells found in our Galaxy (Heiles 1979).

Two nearly face-on, large galaxies which have recently been observed in HI and are excellent candidates for a study of the structure of the HI, are the ScI galaxies M 101 and NGC 6946 (Kamphuis, Sancisi and van der Hulst, in preparation). Both have several very large star forming regions along well defined, massive spiral arms. The HI extends farther than the Holmberg radius in both galaxies and shows spiral structure even outside the optical image. The HI column density distributions of these galaxies are shown in Figure 2. The resolution is 15″ or 500 - 700 pc at the distances of these galaxies.

It is obvious from Figure 2 that the HI disks of M 101 and NGC 6946 have tens of large holes with sizes of 1 to more than 5 kpc. Some of the large holes are ambiguous and could equally well be considered as inter-arm regions. Most of the holes are located near regions of high column density, which probably is a selection effect. The HI disks give the impression that there is a network of holes, and it is quite

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

conceivable that the general structure of the ISM in galaxies like M 101 and NGC 6946 is very filamentary, quickly giving the impression of being full of holes and shells. The large, well defined holes occupy about 10% of the disk and are located throughout the whole HI disk, even in the outer regions where the spiral arms are barely visible in the optical. There is no strong correlation between large holes and OB associations and HII regions.

HIGH VELOCITY GAS

Nearly face-on galaxies are in addition ideal objects to search for gas motions perpendicular to the plane. Radial velocities exceeding the general rotation of the disk could be associated with random motions of the gas in the disk, with expansion (or contraction) of features such as a superbubble or with a collection of high velocity clouds as observed in our Galaxy.

In several face-on galaxies the velocity dispersion of the HI has been measured (cf. van der Kruit and Shostak 1984, Murray, Helou and Dickey 1990). In these galaxies the velocity dispersion appears to be very constant throughout the whole disk with values of 6 - 12 km sec^{-1}.

Superposed on this small, constant velocity dispersion, gas with peculiar velocities has now been found in several nearby galaxies. The most extreme example is M 101 where van der Hulst and Sancisi (1988) discovered two large, high velocity regions within the Holmberg radius. The velocities of these gas complexes range up to 160 km sec^{-1} redshifted with respect to the rotation of the disk. The HI masses involved are 2 10^8 $M_\odot$ and the kinetic energies are of the order 10^{55} ergs. The velocity structure of these regions suggests a connection with the underlying holes in the disk. New, more sensitive observations reveal that these two regions are probably one large (40 $\times$ 20 kpc) complex covering almost half of the optical disk (Sancisi et al. 1990). This feature is simply too massive to be caused by winds and supernova blouw-outs. The most likely explanation is that the high velocity gas is caused by a gas-rich object, perhaps a small galaxy, which punched through the disk of M 101. The result is now visible as an outflow. The fate of the outflowing gas could be that it breaks up into small fragments which rain back into the disk forming a population of high velocity clouds in M 101. Evidence for a general population of high velocity clouds similar to the HVCs in our Galaxy has, however, not been found in M 101.

There is no systematic correspondence between the gas with excess velocities and star forming regions. The majority of the holes in the HI distribution of M 101 show at most moderate (10 - 30 km sec^{-1}) velocity deviations with respect to the bulk HI in the disk. So far there is one glaring exception (Kamphuis, Sancisi and van der Hulst, in preparation): the hole at the edge of the giant HII region NGC 5462, marked in Figure by a small arrow, shows clear evidence for systematic blue- and redshifted gas indicating systematic expansion with velocities up to 80 km sec^{-1}. Figure 3 shows a position-velocity map across this hole at a position angle of 27 degrees. The expanding shell structure is immediately obvious from this Figure. Supernova SN 1951h is located inside the superbubble. The total HI

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

mass and kinetic energy involved are of the order 10^7 $M_\odot$ and a few 10^{53} ergs, respectively, implying that at least several hunderd supernova events would be required to produce it. This is not inconceivable: the neighbouring HII region, for comparison, is powered by the equivalent of 630 O5 stars (Israel et al. 1975).

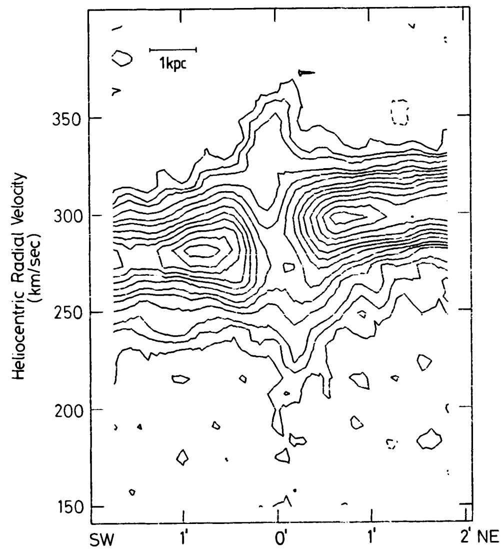

Figure 3. Position - velocity diagram centered on the hole near the giant HII region NGC 5462 in M 101, indicated by the arrow in the left panel of Figure 2. Contour levels are -5, 5, 10, 15, 25, 35, 45, 60, 75, 90, 110, 130, 150, 170 mJy/beam.

The other ScI galaxy observed in detail, NGC 6946, contains at least 9 regions with gas at velocities clearly deviating from the general rotation (Kamphuis, van der Hulst and Sancisi, in preparation). Most of the velocity deviations are associated with holes and range from 30 to 80 km sec^{-1}. The peculiar velocities are either red- or blue shifted, but not both at the same location. The HI masses and kinetic energies involved are of the order of 10^7 $M_\odot$ and 10^{53} ergs, respectively. There is one HI feature covering a large area and showing no clear connection with underlying structures of the disk. An example of high velocity gas is shown in Figure 4, which is a position-velocity diagram at the location indicated in the right panel of Figure 2.

A third example of a galaxy with high velocity gas is NGC 628 (Kamphuis and Briggs, in preparation). The outer parts of the extended gas disk in this object are heavily distorted. The inner part, however, behaves normally as a flat, rotating disk. In this inner region Kamphuis and Briggs discovered at least three gas

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

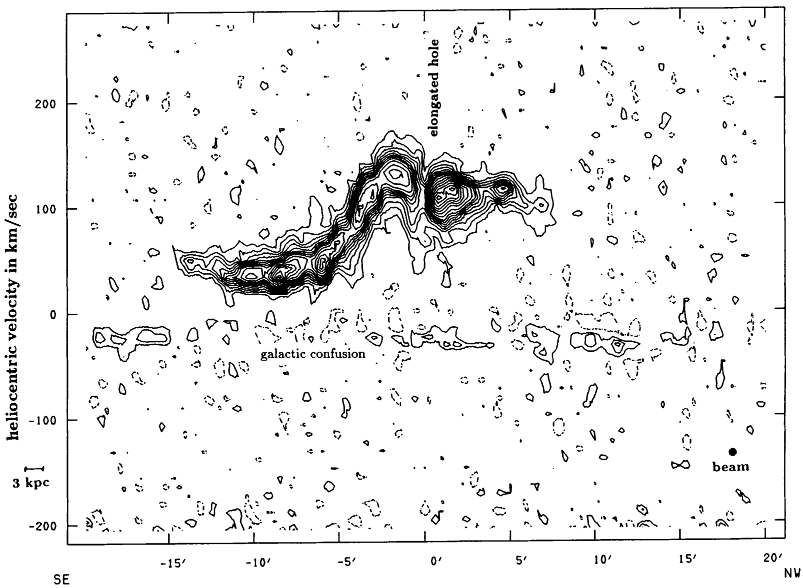

Figure 4. Position - velocity diagram (position angle = -48°, contour levels are -2 to 16 mJy/beam in steps of 2 mJy/beam, followed by 19 to 43 mJy/beam in steps of 4 mJy/beam) centered on the elongated hole in NGC 6946 at $\alpha = 20^h\ 33.4^m\ \delta = 59°\ 59.4'$ (see the right panel of Figure 2).

complexes with anomalous velocities up to 50 - 70 km sec^{-1}. The association with the underlying disk is not clear, due to the relative low angular resolution of the observations. Outside the Holmberg radius, two high velocity gas complexes have been found at the eastern and western edge of the galaxy. Each of these regions have a few 10^7 $M_\odot$ of HI and velocity excesses of 100 km sec^{-1}. The outer regions of NGC 628 are in addition heavily warped (see also Shostak and van der Kruit 1984). The symmetric placement of the two outer high velocity gas complexes suggests an explanation in terms of a tidal model, perhaps resulting from capture of a small companion.

The large distance to galaxies such as M 101, NGC 6946 and NGC 628 limits us to finding only the larger scale high velocity features. A closer look at the HI synthesis data of M 33 (Deul and van der Hulst 1987) now reveals that fainter, smaller features can be found in addition to the expanding gas associated with the holes discussed by Deul and den Hartog (1990). About a dozen regions have been located in a preliminary analysis of the data. These are not clearly associated with star forming regions. An example is shown in Figure 5, which is a right ascension-velocity map centered in the south-east of M 33. This map shows both a hole (at $\alpha = 1^h\ 30^m\ 30^s$) and a high velocity gas cloud (at $\alpha = 1^h\ 30^m\ 40^s$). The radial velocity of the gas cloud (uncorrected for projection effects) is 80 km s^{-1} with

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

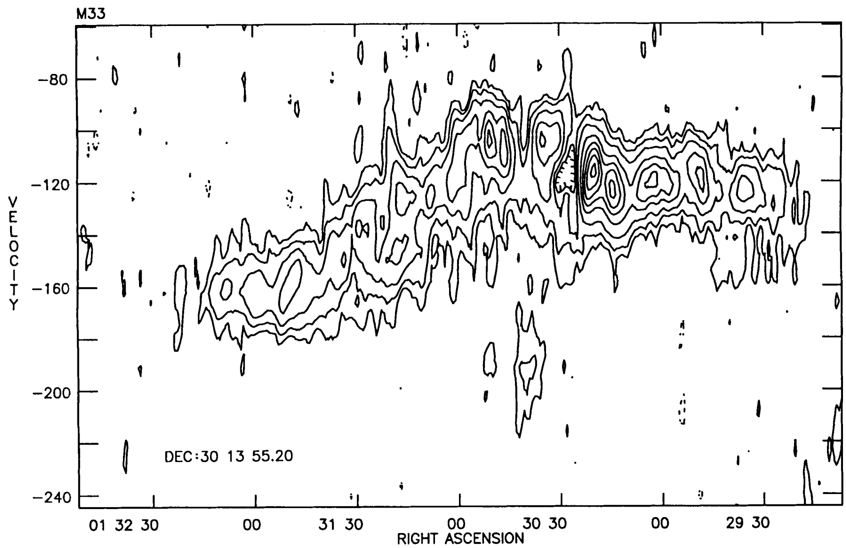

Figure 5. Right Ascension - velocity diagram at a Declination of 30° 24′ 11.23″ showing high velocity gas in M 33. Contour levels are -21.3, 21.3, 42.6, 85.2, 170.4, 255.6, 340.8, 426.0, 511.2 mJy/beam. Relative minima are hatched.

respect to the bulk rotation. The HI mass involved is 5.6 10^5 $M_{\odot}$. Such a feature is much more in the range of parameters found for the HVCs in our galaxy.

DISCUSSION

The holes

It is clear from HI observations of nearby spiral and irregular galaxies, that large holes in the HI distribution are not uncommon. The number found in galaxies varies from a few to dozens and more (Table 1). In some galaxies the large holes are concentrated at large galactocentric distances (e.g. our Galaxy, M31 and M 33), but in other galaxies, they are randomly distributed throughout the disk (e.g. M 101, NGC 6946). Some of the larger "holes" are not real holes but rather inter-arm regions and should be excluded from the population of structures which is created by explosive events. The area covered by the (well defined) large holes is of the order of 15% of the disk or less. It is quite conceivable that the galaxies described in the previous section also have a collection of smaller holes, such as seen in our Galaxy, M 31 and M 33, covering a larger fraction of the disk. The limited angular resolution unfortunately prevents us from detecting those.

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

Assuming that all of these large holes (diameter > 500 pc) are caused by stellar winds and/or supernova explosions, the energies required are such that most of them are classified as supershells (E > 3 10^{52} ergs, Heiles 1979). The missing (partly driven out) HI masses are of the order of 10^6 - 10^8 $M_\odot$. The lifetimes of the large holes, derived from their linear sizes and expansion velocities, vary from about 10^7 to a few 10^8 years. Since most of the large holes show a lack of correlation with present star formation, another lower limit to the age for these holes is the lifetime of an HII region ($\approx$ 2 10^7 years). The upper limit comes from the time needed for the surrounding gas to fill in the holes. Approximate values for some of the parameters of the large holes are given in Table 1.

Table 1. Parameters of large holes (> 500 pc) in nearby galaxies

Galaxy	Number[a]	Max. sizes (kpc)	Missing HI masses[b] ($10^6 M_\odot$)	Energies[c] (10^{52} ergs)	Ages[d] (10^7 yr)
M 101	> 30	> 3	2 - 100	4 - 1100	2 - 15
NGC 6946	> 20	5	5 - 200	14- 5300	2 -25
IC 10	2	0.8	1.7 - 3	5 - 30	2.5 - 2.8
M 31	< 15	1.2	0.9 - 6.6	2 - 19	1 - 4
M 33	< 16	1.2	0.3 - 11	0.7 - 50	1 - 10
SMC	3	1.6	2 - 12	20 - 600	1.5 - 2.5
Our Galaxy	34	2.6	2 - 50	0.5 - 160	2 - 13

Notes: *a Including possible inter-arm regions*
b Calculated as $\pi R^2{}_{\rm hole} \times$ *thickness disk* $\times$ *average ambient HI density*
c Based on elliptical shaped holes, following calculation of Heiles (1979)
d Estimated as $R_{\rm hole}/V_{\rm expansion}$

If holes like the ones discussed above result from explosive events which break out of the disk one does not expect to find sizes much in excess of 5 - 6 times the scale height of the HI gas layer (Mac Low, McCray and Norman 1989, Heiles 1990). The sizes found are, however, a few kpc and much larger than the generally assumed thickness of the cool HI disk.

The origin of such large holes is not clear. Superbubbles in the outer parts may have larger sizes due to flaring of the HI layer. The large holes in the inner parts require another explanation. One possibility is that the thickness of the HI layer is larger than a few hundred parsecs such as suggested for our Galaxy (Lockman 1984 and this volume). Another possibility is that the higher star formation rate in the inner parts causes superbubbles to overlap so they show up as very large cavities. A third possibility is that another mechanism, such as a dominant magnetic field (cf. Cox 1990), prevents the hot gas from escaping into the halo and tends to keep the gas down into the disk.

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

Not all of the holes show evidence for expansion. This could imply that the gas with anomalous velocities is diffuse so that the observations do not pick it up, or that the holes are old and have stopped expanding. The maximum velocity excesses found associated with a minor fraction of the holes are 50 - 80 km sec^{-1}. None (with the exception the hole near NGC 5462) of the observed velocity deviations are symmetric: they are either blue or redshifted. These asymmetries may imply that the supernova explosions driving the gas out are not in the midplane of the disk or that the ambient HI (and the molecular cloud distribution) is very clumpy.

The High Velocity Gas

High velocity gas features have been found in other galaxies. The edge-on galaxies examined here do reveal some large HI features extending up to 5 kpc above the plane and the face-on galaxies do occasionally show large high velocity complexes. These complexes are, however, larger and more massive than the HVC complexes in our Galaxy, except for the feature found in M33. The reason for not finding a wide-spread population of gas clouds in other galaxies similar to the HVCs in our Galaxy may be a result of the limited sensitivity and resolution which restricts us to only finding HI complexes of 10^6 $M_\odot$ or more. This would imply that the high velocity complexes found occasionally in other galaxies represent the upper extreme of the HVC mass spectrum. If on the other hand the Galactic HVCs are not as distant as assumed one would not expect to find similar features except in the nearest galaxies such as M31 and M33. A third possibility is that high velocity clouds are not a general phenomenon in spiral galaxies.

The larger high velocity gas complexes such as observed in M 101 and NGC 628 suggest that galaxies may suffer episodic accretion of large gas clouds or gas rich, dwarf galaxies (Sancisi 1990, Sancisi et al. 1990). Such events do throw gas out of the disk into the halo and provide a mechanism for occasional feeding of the gas halo of galaxies.

We are entering an era of very fruitful research focussing on problems related to the interstellar medium in nearby galaxies. This review did not address all possible issues but is intended to outline the important first results which have emerged from detailed observations of the HI in a small number of nearby galaxies. These first results discussed in this review clearly illustrate that further work in this field is important and fruitful, and is expected to broaden our insights in the years to come.

ACKNOWLEDGEMENTS

We thank A. H. Broeils and M. Rupen for the use of unpublished data and thank R. Sancisi for his comments on an earlier version of this manuscript. We appreciate the help of G. Comello, W. Haaima and G. Tamminga for preparing the figures.

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press

REFERENCES

Allen, R.J. and Goss, W.M.: 1979, Astron. Astrophys. Suppl. **36**, 135.
Bregman, J.N.: 1980, Astrophys. J. **236**, 577.
Brinks, E.: 1981, Astron. Astrophys. (Letters) **95**, L1.
Brinks, E. and Bajaja, E.: 1986, Astron. Astrophys. **169**, 14.
Cox, D.P.: 1990, in *The Interstellar Medium in Galaxies*, ed. H. A. Thronson and J. M. Shull, Kluwer Ac. Publ, p. 181.
Dettmar, R.J.: 1990, Astron. Astrophys. (Letters) **232**, L15.
Deul, E.R. and van der Hulst, J.M.: 1987, Astron. Astrophys. Suppl. **67**, 509.
Deul, E.R. and den Hartog, R.H.: 1990, Astron. Astrophys. **229**, 362.
Dickey, J.M., Murray Hanson, M. and Helou G.: 1990, Astrophys. J. **352**, 522.
Dopita, M.A., Mathewson, D.S. and Ford, V.L.: 1985, Astrophys. J. **297**, 599.
Duric, N., Seaquist, E.R., Crane, P.C., Bignell, R.C. and Davis, L.E.: 1983, Astrophys. J. (Letters) **273**, 574.
Heiles, C.: 1979, Astrophys. J. **229**, 533.
Heiles, C.: 1984, Astrophys. J. Suppl. **55**, 585.
Heiles, C.: 1990, Astrophys. J. **354**, 483.
Hindman, J.V.: 1967, Aust. J. Phys. **20**, 147.
Irwin, J.A. and Seaquist, E.R.: 1990, Astrophys. J. **353**, 469.
Israel, F.P., Goss, W.M. and Allen, R.J.: 1975, Astron. Astrophys. **40**, 421.
Lockman, F.J.: 1984, Astrophys. J. **283**, 90.
Mac Low, M., McCray, R. and Norman, M.L.: 1989, Astrophys. J. **337**, 141.
McGee, R.X. and Milton, J.A.: 1966, Aust. J. Phys. **19**, 343.
Meaburn, J.: 1980, Mon. Not. R. Astr. Soc. **192**, 365.
Meaburn, J., Marston, A.P., McGee, R.X. and Newton, L.M.: 1987, Mon. Not. R. Astr. Soc. **225**, 591.
Mirabel, I.F. and Morras, R.: 1990, Astrophys. J. **356**, 130.
Rand R. J., Kulkarni, S. R. and Hester J. J.: 1990, Astrophys. J. **352**, L1.
Rohlfs, K., Kreitschmann, J., Siegman, B.C. and Feitzinger, J.V.: 1984, Astron. Astrophys. **137**, 343.
Sancisi, R.: 1990, in Proceedings Erice Workshop *Windows on Galaxies*, ed. Fabbiano, G., Gallagher, J. and Renzini, A., Kluwer Ac. Publ., in press.
Sancisi, R., Broeils, A. H., Kamphuis, J. and van der Hulst, J.M.: 1990, Proceedings of the Heidelberg Conference on *Dynamics and Interactions of Galaxies*, ed. Wielen, R., Springer., p. 304.
Shostak, G.S. and van der Kruit, P.C.: 1984, Astron. Astrophys. **132**, 20.
Shostak, G.S. and Skillman, E.D.: 1989, Astron. Astrophys. **214**, 33.
Tenorio-Tagle, G. and Bodenheimer, P.: 1988, Ann. Rev. Astron. Astrophys. **26**, 145.
Tenorio-Tagle, G., Franco, J., Bodenheimer, P. and Rozyczka, M.: 1987, Astron. Astrophys. **179**, 219.
van der Hulst, J.M. and Sancisi R.: 1988, Astron. J. **95**, 1354.
van der Kruit, P.C. and Shostak, G.S.: 1984, Astron. Astrophys. **134**, 258.
van Woerden, H., Schwarz, U.J. and Hulsbosch, A.N.M.: 1985, in *The Milky Way Galaxy, IAU Symp* **106**, eds. H. van Woerden, R.J. Allen, W.B. Burton, p. 387.
Wakker, B.P.: 1990, Ph.D. thesis Groningen University.
Wakker B.P., Broeils, A.H., Tilanus, R.P.J. and Sancisi, R.: 1989, Astron. Astrophys. **226**, 57.

https://doi.org/10.1017/S0074180900089099 Published online by Cambridge University Press